# WIND TUNNEL AND NUMERICAL EXPERIMENTS EXPLORING THE INTERACTIONS BETWEEN AN EJECTA CURTAIN AND AN ATMOSPHERE

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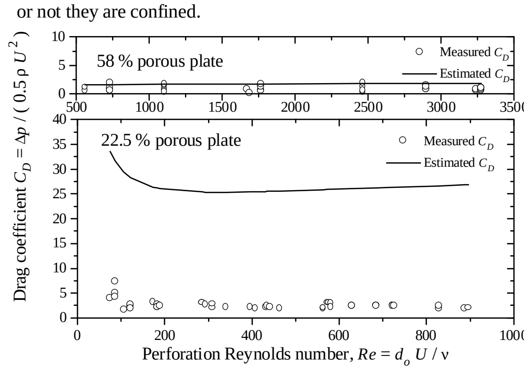
**Abstract** Analyzing the flow past small porous plates provides the groundwork for understanding the interactions between an atmosphere and an ejecta curtain at planetary scales. The present study develops criteria for flow traversing a porous structure, determining wind speed losses when atmosphere flows through the upper semi-permeable portions of an ejecta curtain, and assesses wind speed losses due to atmospheric compressibility. These results permit establishing the amount of ejecta entrainment at broad scales, and the effect of this entrainment on ejecta transport and deposition. Eventually, observed ejecta morphologies of planetary craters formed in an atmosphere will provide information on impact conditions such as target properties (including volatile content) and atmospheric density.

**Introduction** The interactions of an atmosphere with an advancing ejecta curtain probably play a significant role in controlling the entrainment, transport and emplacement of fine grained ejecta at planetary scales [1, 2, 3, 4]. Preliminary estimates of the wind strengths created by an advancing ejecta curtain indicate that a substantial amount of fine grained ejecta should be entrained at planetary scales [3, 5]. Accurate estimates of the amount of ejecta entrained still need to be determined to gain a better understanding of how this entrainment affects ejecta transport and emplacement at broad scales. Using both wind tunnel experiments and computational fluid dynamics (CFDs), this study investigates flow past a variety of inclined solid and perforated plates, which provide good analogs to an ejecta curtain comprised of particulates [5]. This approach allows addressing the physical factors controlling the impermeable length $L$ and velocity $U$ of the ejecta curtain, and the time $t$ just prior to when the curtain becomes permeable. The values $L$, $U$ and $t$ establish the strength of the circulation and entrainment capacity of the vortex ring generated by an advancing curtain [5]. The physical factors controlling $L$, $U$ and $t$ are critical for determining how an ejecta curtain interacts with a realistic atmosphere which would be shock heated early during crater formation, and which decreases in density with elevation.

**Conditions for flow through an ejecta curtain** An atmosphere flows through a porous barrier or ejecta curtain when sufficient pressure difference exists across the barrier to drive flow through its resistant gaps. If the pressure difference across the barrier is too small, the flow moves around. The resistance of an ejecta curtain depends on the size and density of individual particles comprising the curtain, on the velocity of the ejecta curtain, and on the surrounding atmospheric density and viscosity. For a perforated plate, this resistance depends on the porosity of the plate, the shape of perforations, atmospheric viscosity and density [6]. In hydraulics [e.g. 6], the dimensionless parameter controlling the resistance to flow of a barrier is equal to the pressure change across the barrier divided by the upstream dynamic head. This ratio is equivalent to the drag coefficient $C_D$ for a blunt object in an unconfined flow and defines when atmosphere flows through (versus around) an ejecta curtain.

**Wind tunnel and CFD Experiments** Wind tunnel and CFD experiments investigate flow past a variety of plates inclined at 45° into the flow. These investigations allow comparing $C_D$ values of unconfined porous plates (filling little or no portion of a channel) with known $C_D$ values for confined porous plates (filling the entire cross-section of a channel [6]). Such comparisons show that known $C_D$ values [6] for confined porous plates can be used to compare the relative resistance of unconfined porous plates. The wind tunnel experiments also document losses in wind speed as atmosphere flow separates through the upper semi-permeable portion of a perforated plate whose porosity increases with height. Similar losses are expected at the top of an ejecta curtain. Furthermore, the wind tunnel calibrates the turbulent coefficients of the CFD (κ-ε turbulence model) for the plate geometry under investigation.

Figure 1: Estimated and measured drag coefficient of two perforated plates. Similar variations in drag coefficient indicate that the same physics controls the passage of flow through the perforated plates regardless of whether or not they are confined.




The CFD calculations estimate the flow speeds in a truly unconfined (ejecta-like) environment which cannot be achieved in the wind tunnel since the inclined plates slightly obstruct its cross-sectional area. The

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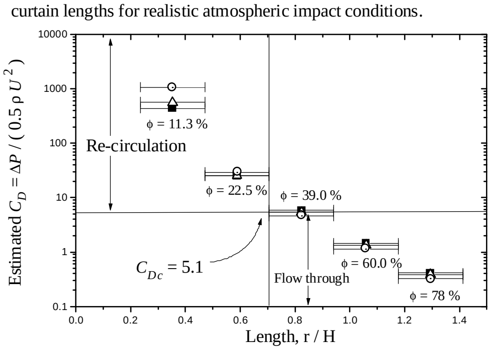
CFD calculations also show whether or not flow separation occurs at the top of a planetary scale ejecta curtain when the flow becomes compressible but nonetheless remains subsonic. Furthermore, they provide corrections if compressible flow effects alter the strength of the vortex ring generated by an ejecta curtain.

The wind tunnel experiments were performed in a 0.5x0.5m tunnel at the Cold Regions Research and Engineering Laboratory. We used a manometer to measure pressure losses across the plates and a hot wire anemometer to measure wind speeds around the plates. Both wind tunnel and CFD experiments were performed at steady state. The CFD calculations were done using the commercially available code FLUENT.

**Results** The wind tunnel experiments show that the known $C_D$ behavior for confined plates [6] is reproduced at unconfined perforated plates (Figure 1), thereby indicating that the same physics controls the resistance to flow of both plates. Consequently, known $C_D$ values [6] for confined porous barriers (including those made of unconsolidated material closely resembling an ejecta curtain) can be used to compare the relative resistance of unconfined porous obstacles. The absolute value of these $C_D$ values, however, do not reflect the true magnitude of the pressure drop across the unconfined obstacles (see Figure 1) because recirculation behind such obstacles reduces the pressure change across them.

Figure 2: Estimated drag for a plate whose porosity $\phi$ increases along its length showing for what conditions flow goes through the plate. $C_{Dc}$ allows estimating curtain lengths for realistic atmospheric impact conditions.




The $C_D$ values for confined porous plates permit comparing relative $C_D$ values for a variety of unconfined porous plates. Hence, the $C_{Dc}$ that defines when atmosphere flows through a plate whose porosity increases with its length, also defines the impermeable height of an ejecta For such a plate, flow passes through its 40% porous layer when $C_{Dc}$ = 5.1 (Figure 2). The estimated curtain length obtained using this $C_{Dc}$ value duplicates (within a factor of 2) observed ejecta curtains witnessed in experiments of the NASA Ames vertical gun range. Any difference between the observed and estimated curtain height occurs because of our assumption that the excavated ejecta volume retains the same porosity measured in the pre-impact target. A more realistic value for the curtain porosity results in a better match between the observed and estimated curtain height. Just as $C_{Dc}$ sets the curtain length, it also controls the time when the ejecta curtain becomes permeable.

Figure 3: Flow velocity losses due to passage through a semi-permeable section at top of plate with increasing porosity $\phi$. The energy losses are about 8 %. The flow structure past an inclined plate is independent of Reynolds number. Velocity profile taken at x* = x / H = 1.6.

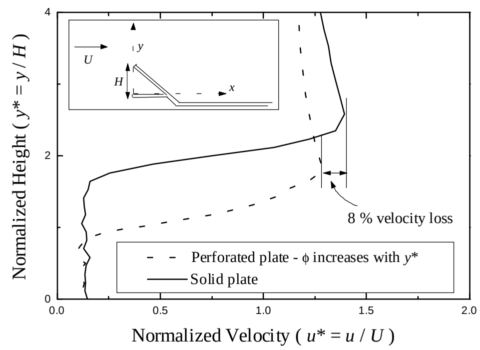



Figure 3 shows how the top semi-permeable portion of a plate whose porosity increases with height reduces the wind velocity generated as atmosphere flows through it. All the wind speeds have been corrected for blockage effects in the wind tunnel. The maximum flow velocity through the porous plate is 8% less than the maximum wind speed past the solid plate. This wind speed loss needs to be included when estimating the circulation and entrainment strength of the vortex ring generated by an advancing ejecta curtain at large scales.

Properly benchmarked with wind tunnel results, the CFD calculations reveal that flow separation still occurs when compressibility becomes important. They also show that fluid compressibility decreases the maximum wind speed generated during flow separation with respect to its incompressible counterpart.

**References**: [1] Schultz, P.H. and D. Gault (1979) *JGR 84*, 7669-7687. [2] Schultz, P.H. and D. Gault (1982) *Spec. Pap GSA 190*, 153-174. [3] Schultz, P.H. (1992a) *JGR 97*, 11623-11662. [4] Schultz, P.H. (1992b) *JGR 97*, 16183-16248. [5] Barnouin-Jha, O.S. and P.H. Schultz (1996) *JGR 101*, 21099-21115. [6] Idelchik, I.E. (1994) *Handbook of Hydraulic Resistance*.